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CANDIDATE FABRICS FOR THE 2ND GENERATION EXTENDED COLD WEATHER CLOTHING SYSTEM

By
Margaret A. Auerbach
and
Regina D. Jugueta

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SURVIVABILITY DIRECTORATE

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A literature search was conducted during the summer of 1995 to find potential candidate fabrics and materials for the 2nd Generation Extended Cold Weather Clothing System (ECWCS). The objective was to find alternative materials for the ECWCS which would drastically reduce the weight and bulk of the current system, while providing improved environmental protection over a wide spectrum of climatic conditions. Several materials were indentified that showed potential; however, materials testing is needed before a complete evaluation of the materials can be made.

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BATTINGS	ENVIRONMENTAL CONDITIONS	BULK REDUCTION
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PREFACE

This report summarizes a literature search conducted during the summer of 1995 to find potential candidate fabrics and materials for the 2nd Generation Extended Cold Weather Clothing System (ECWCS). Candidates were sought for the current ECWCS system which consists of four layers: 1) the polypropylene shirt and trouser underwear, 2) fiberpile shirt and bib overall, 3) field liner coat and trousers and 4) standard parka and trouser outer shell fabric. (There is a cold weather trouser which can be worn over the trouser liner when the outer ECWCS trouser is not needed. However, candidates for this layer were not sought.) The candidate fabrics must be highly technical, state- of-the art fabrics which will protect the individual soldier under a wide range of environmental conditions, while reducing the weight and bulk of the system and must possess the ability to perform in an integrated multiple layered protective ensemble.

The objective of the 2nd Gen ECWCS program is to drastically reduce the bulk and weight of the current ECWCS system while providing improved environmental protection over a wide spectrum of climatic conditions. The ECWCS system currently consists of the four layers mentioned above and is designed to provide protection from -60 to +120 °F.

The current ECWCS system will be considered the control samples for this study. All candidate fabrics must demonstrate equal to or better performance than the designated layer used in the current ECWCS system.

All candidate fabrics will be discussed in relation to the ECWCS layers they could potentially replace.

NOTE: As this is a literature search, most of the data and claims made in this report were obtained from the manufacturer and do not represent the Army's position. Data provided by the manufacturer has not been verified through testing unless indicated or generated by a government facility. Test methods used to obtain data are indicated when available. Since different test methods were used by the individual manufacturers to obtain test results, most of the data generated is not directly comparable.

CANDIDATE FABRICS FOR THE 2ND GENERATION EXTENDED COLD WEATHER CLOTHING SYSTEM (ECWCS)

Layer 1: Underwear Layer

The first layer is the underwear layer. The Extended Cold Weather Clothing System (ECWCS) currently uses Drawers, Cold Weather, Undershirt, Cold weather: Polypropylene (A-A-55246). The basic material of the drawers and undershirt can be found in this Commercial Item Description (CID). It is a circular or warp knit terry loop fabric of 100% textured or non-textured multifilament polypropylene in both the face and terry -loop backing. The terry-loop backing is brushed and worn on the inside. The cloth weighs 5.9 (min) oz/sq yd. A 1x1 rib knit polypropylene is used for the cuffs with a weight of 5.3 -0.5 +1.5 oz/sq yd. The design features include: pants: elastic polyester webbing for waistband, bartacking at the top and bottom of fly, knit cuffs; shirt: raglan sleeves, one piece collar that converts to a turtle neck when the front zipper is closed, knit cuffs. Both the drawers and undershirt are available in sizes XSM - XLG. Table 1 lists the standard requirements for the underwear layer currently used in the ECWCS.

Table 1. Layer 1: Underwear-Standard Requirements

Characteristic	Requirement	Test Method
Weight (oz/sq yd)	5.9 (min)	ASTM-D 3776
Bursting Strength (lbs)	80 (min)	ASTM-D-3787
Shrinkage		AATCC96,(Test Ic,A)
Drawers	4% (max)	
Undershirt	3% (max)	
Colorfastness to:		
Laundering	4 (min)	AATCC 61 (Test 1A)
Perspiration	4 (min)	AATCC 15
Crocking	4(min)	AATCC 8
ph Value	5.0 to 8.5	Fed TM 2811

The following describes potential materials and fibers that can be considered as replacements for this layer. There are three major fibers used in these underwear fabrics: polyester, nylon or polypropylene. Some are blended, treated or chemically modified to achieve the wicking and other desired properties of an underwear fabric.

Polyester:

Du Pont makes three polyester fibers which are engineered for underwear (as well as other) fabrics - Thermax^{cm}, Coolmax^{cm}, and Thermastat^{cm}. Thermastat and Thermax use round hollow polyester fibers and have inherent wicking properties. Coolmax uses a four-channel solid fiber which forms conduits to move moisture and must be in direct contact with the skin to be effective. DuPont claims all of these fibers provide good breathability, wick moisture (perspiration) away from the body thus retaining body heat and preventing the "chilling effect", and can be machine washed and dried without shrinking. Thermastat, the "new generation of Thermax", uses microdenier fibers 0.5 - 0.7 dpf providing the same insulating properties as Thermax (1.2 - 2.0 dpf), but providing a lighter weight, less bulky material. According to DuPont, because there are more fibers/inch the wickability of the Thermastat material is also improved. Thermax/Thermastat fabrics come in varying weights and thicknesses: light, medium and heavy (fleeced). Test data on Thermax and Thermastat, as well as other samples, evaluated for the lightweight cold weather underwear program which will be discussed later can be found in Tables 2& 3. Note that different test methods were used to evaluate these materials. ISO 11092 used to obtain the data in Table 3 is the test method which is now considered the "standard test method". Prior to this, ASTM D1518, which was used to obtain the data in Table 2, was considered the "standard test method".

Table 2. Lightweight Cold Weather Underwear Data

Material	Fiber Content Construction	Weight (oz/sq yd)	Clo		Im/clo	
			Before Launder	After Launder	Before Launder	After Launder
Thermax	100% polyester rib knit	4.7	0.71	0.79	0.715	0.639
Capilene	100% polyester Microbial finish rib knit	4.5	0.65	0.7	0.804	0.686
Polypropylene	100% spun polypropylene (Coville) interlock knit	4.9	0.72	0.78	0.769	0.613
Thermastat	100% polyester rib knit	5.4	0.68	0.72	0.778	0.658
Thermax	50/50 poly/wool bi-ply, jersey knit	6.9	0.71	0.86	0.691	0.544
Akwatek	100% polyester rib knit	4.7	0.7	0.7	0.739	0.682

Navy Data[1]
Tested According to ASTM D1518. Average of 3 samples.

Capilene® polyester fibers by Patagonia® are chemically altered to make them hydrophilic ("water loving"). The outside attracts water while the untreated core repels it. Therefore, moisture is lifted and dispersed. An antimicrobial finish inhibits odor-causing bacteria. The manufacturer claims it's easy to clean and minimal shrinkage occurs. It is available in heavyweight stretch, midweight stretch, expedition weight (brushed on inside), midweight, lightweight, and silkweight. Capilene was tested by the U.S.Navy for the United States Marine Corps for use as a lightweight cold weather underwear[2]. The Marines were looking for a material that would provide less thermal and water vapor resistance than the standard ECWCS polypropylene material. The Capilene material provided approximately 50% less thermal and water vapor resistance than the standard (as did the Wickers Style 1236 (Akwatek fiber)which will be discussed later). The Capiliene fabric was adopted for this application. See Tables 2 & 3 for test data.

Wellman, Inc. manufactures and sells polyester fibers marketed under the Fortrel® brand. Some of their products include Fortrel®, Fortrel® Ecospun™, and ComFortrel®. ComFortrel is a 1.2 denier polyester. Wickers Sportswear uses ComFortrel fibers that have been molecularly modified by a process developed by Comfort Technologies referred to as Akwatek in thermal underwear fabrics. According to Comfort Technologies, the Akwatek treatment process molecularly modifies the fiber to move water away from the body using a process called electrochemical transport. Here, molecules of water are separated and moved using positive and negative charges. This separation of water molecules allows excess moisture to be drawn away from the skin so wetness is not felt by the wearer. Akwatek-treated polyester can adjust to different regions of the body heating one while cooling another, based on perspiration rate and ambient conditions and will alter as activity changes. The body temperature adjusts to warmer climates through the cooling effect of the evaporation of moisture provided by perspiration - the higher the rate of perspiration the faster the Akwatek treated fabric works to draw moisture away from the body. The evaporation of moisture from the surface of the fabric as well as the one that occurs directly off the skin of the body have a combined effect. In actuality, this dual action can cause the wearer to perspire less but with a doubled cooling effect. Akwatek treated fibers do not need to be worn close to the skin to transport moisture. Based on wash tests conducted at the International Fabricare Institute, garments exhibit progressive pilling and fuzziness, when laundered using hot water. The pilling and fuzziness is minimal when laundered with warm water. Style 1722 from Wickers Sportswear is 5.9 oz/sq yd and contains 95% ComFortrel polyester rib and 5% Lycra Spandex. It has a four-way stretch that can be worn by itself or in a layering system. Other styles and compositions consist of 100% ComFortrel

polyester, 95% ComFortrel polyester rib and 5% Lycra (6.5 oz/sq yd) and 100% ComFortrel Expedition Weight Fleece (9.0 oz/sq yd).

As mentioned, Atwatek-treated fabrics were tested by the Navy for the US Marine Corps[2]. The Navy conducted a guarded hot plate evaluation to measure the thermal and water vapor resistance before and after fifteen launderings. The objective of the study was to find a fabric which would provide less thermal and water vapor resistance than the standard polypropylene (ECWCS) material for use as a light weight cold weather underwear. According to the Navy's results (see Table 3), Style 2236 and 1236, both containing the Akwatek treatment, were found to be candidates for the light weight cold weather underwear. Style 1236 showed approximately 50% less thermal and water vapor resistance than the standard polypropylene (ECWCS) fabric and style 2236 provided 20% less thermal and water vapor resistance than the standard. Less thermal resistance will allow the body to cool at a faster rate and less water vapor resistance will allow greater evaporative cooling during periods of increased activity.

Table 3. Lightweight Cold Weather Underwear Test Data

Material	Fiber Content	Weight	Thermal Resistance		Water Vapor Resistance	
	Construction	(oz/sq yd)	Rct		Ret	
			Before Launder	After Launder	Before Launder	After Launder
STANDARD	Polypropylene	7.3	0.083	0.086	9.4	9.52
	1x1 rib - brushed jersey					
Wickers Style 2236	ComFortrel polyester	7.5	0.069	0.069	7.26	7.52
	Akwatek					
	interlock,brushed fleece					
Wickers Style 5606	ComFortrel polyester	4.5	0.037	0.051	4.23	5.04
	Akwatek					
	1x1 rib knit					
Wickers Style 1236	ComFortrel polyester/Lycra	7	0.04	0.041	4.76	5.11
	Akwatek					
	interlock					
Wickers Style 1027	Polypropylene	4.7	0.04	0.045	4.58	5.92
	1x1 rib knit					
Milliken	Capilene polyester 1x1 rib knit	4.5	0.036	0.037	4.47	4.6

Testing conducted by NCTRF (Navy Clothing and Textile Research Facility)
According to ISO 11092[2]
Laundered 15 times using Navy Shipboard Formula II - A milnor washer /extractor 140 F and a Huebsch gas dryer 140 - 170 F.

Dri-On™ by MontBell pulls moisture from the skin, and bounces the moisture along the fibers. An O.F.T.™ (Odor Fighting Thread) can be incorporated whereby catalytic agents are added to polyester fibers to reduce odor-producing bacteria.

Hoechst Celanese has several Trevira® polyester microfibers available to be made into fabrics for various end use applications. Trivera® Microfilament produces knit fabrics which are light in weight; shrink, mildew and odor resistant; and washable. Hoechst claims to have a dynamic wicking action which lets interior moisture out but prevents exterior moisture from coming in. Trevira® Microtherm is a microdenier (less than 1 denier) polyester lining fabric. Because of its low thermal conductivity, it feels warmer to the touch. The manufacturer claims the larger surface area of Microtherm wicks away moisture faster than other linings, is fully washable and will not shrink. Because these fabrics use microdenier fibers, they provide added wind and water resistance and allow perspiration to evaporate. According to data received from Hoechst Celanese, Microtherm has better wicking properties than Thermastat but comparable thermal properties.

Malden Mills makes a series of knit fabrics under the Polartec name. Series 100 is the layer designed to be worn next to the skin. These fabrics have a finish which actively wicks perspiration away, channeling moisture away from the body and are brushed to minimize touch points with the skin where water can get trapped. Data on the Series 100 fabrics can be found in Table 4.

Polyolefin:

The following properties are inherent in polyolefin fabrics: 1) wickability - will not absorb perspiration, transfers moisture to the surface of the fabric where it evaporates; 2) has a low specific gravity (34% lower than polyester), therefore is light weight; 3) has a low thermal conductivity (15% lower than polyester); 4) is stain resistant, repels dirt; 5) is odor resistant; 6) has good abrasion resistance; 7) has low static properties; 8) is impervious to most chemicals; 9) is mildew resistant; 10) is machine washable/rapid drying and 11) textured filament yarns eliminate pilling, linting and provide resistance to snagging.

Coville Inc. produces a fabric made of anti-microbial polyolefin filament yarns called AM Microstop ™. This fabric incorporates antimicrobial agents (Microban®) into the molecular structure of the polyolefin which strike unwanted microorganisms including staph, E coli, fungus, and yeasts interrupting their

Table 4. Polartec Fabrics

Style	Description	Weight (oz/sq yd)	Fiber Content	Laundering	Colorfastness Crocking Wet	Colorfastness Crocking Dry	Light (20hours)	Flammability	Thickness (in)	Stretch Width%	Stretch Length%	Shrinkage Length%	Shrinkage Width%	Air Permeability (cu ft/sq ft/min)	Clo
Test Method				AATCC-61	AATCC -8			AATCC-33	TM 5030	ASTM D2594		AATCC 135 3x 120F		ASTM D737-75	ASTM D1518
Series 100															
7420	lightweight mesh construction	4.1	100% Polyester	4	5	5	5	Class 1	0.045	80	20	4	4	N/A	N/A
	jersey face, brushed polyester back														
	good stretch, Polartec NTS wicking and anti-microbial treatments														
7504	midweight mesh construction	5.2	100% Polyester	5	5	5	5	Class 1	0.053	80	20	3	3	N/A	N/A
	polyester jersey face, brushed polyester back														
	Polartec NTS wicking and anti-microbial treatments														
	BiPolar Technology - best next to the skin fabric														
7548	expedition weight double velour	5.5	100% Polyester	4	5	5	5	Class 1	0.16	60	NA	3	3	254	1.057
	wicking and anti-microbial protection for next-to the skin														
Series 200															
7614	double-sided, medium weight velour pile	7.5	100% Polyester	4	5	5	4	Class1	0.2	60	N/A	3	3	247	1.2
7590-2	double sided medium weight velour pile	7.8	100% Polyester	5	4	4	4	Class 1	0.23	60	N/A	2	2	325	1.21
	at least 89% recycled polyester														
	Durable water repellent finish														
Series 300															
7593/7594	double faced pile	10.2	100% Polyester	4	5	5	4	Class 1	0.275	60	NA	3	3	203	1.32
	at least 89% recycled polyester														
7529	double sided shearling pile (high in front - low in back)	11	100% Polyester	4	5	5	4	Class1	0.274	60	N/A	3	3	200	1.465
	anti-microbial properties														
Series: Power Stretch															
7767	nylon jersey front - velour back (low pile)	6.6	60%Polyester	4	5	5	4	Class 1	0.103	60	60	3	3	163	0.953
	inner pile has wicking, anti microbial protection		30% Nylon												
7622	Series 200 double faced velour pile with stretch	6.8	94% Polyester	4	5	5	5	Class1	0.227	60	N/A	3	3	210	0.975
			6% Lycra												
Series: Windbloc															
7774	double faced velour with intermediate barrier	9.9	100% Polyester	4	4	4	5	Class 1	0.192	20	N/A	2	2	0	1.275
	windproof, durable water repellent finish on face														
	Moisture Vapor Transmission (ASTM E96) 975g/sq m/24 hrs														
	Hydrostatic Resistance (ASTM 751) 25 psi														
Manufacturer data															

ability to function, grow, and reproduce. According to manufacturer claims, the anti-microbial protection is continuous despite abrasion because when "some of the top layer of Microban® particles are removed instantly, the resulting imbalance in the internal vapor pressure pushes new Microban® agents to the surface until equilibrium is reestablished." In addition to this anti-microbial property, the fabric provides those properties inherent to polypropylene.

Helly Hansen makes a line of fabrics called LIFA. LIFA refers to a variety of different garments and materials containing different fibers (polypropylene, polyester, polyamide, polyethylene, and polyvinyl chloride), yarns, thicknesses, knit patterns and fit. The most important property of the underwear is that it transports moisture away from the surface of the skin. Helly Hansen always uses polypropylene next to the skin because it transfers moisture (in the vapor stage) away from the skin to outer garments - it does not absorb water. Basically there are three categories of LIFA moisture management systems - LIFA ATHLETIC, LIFA ARCTIC, and LIFA ACTIVE each designed for different applications. LIFA ATHLETIC is designed to be moisture-transporting. There are two types of LIFA Athletic - ULTRA (available in Europe only) and PROLITE 5000 - both made of 100% polypropylene. These materials are thin and elastic (body hugging) made of an open structure for ventilation. PROLITE 5000 is made of the thinnest staple fiber available (2.2 dtex) and has an elasticity of 300%. PROLITE 5000 comes in a lightweight rib knit (1x1) weighing 4.4 -4.7 oz/sq yd and a medium weight interlock knit (18 cut) weighing 5.3 -5.5 oz/sq yd. The LIFA ARCTIC line concentrates on providing insulation then moisture transport. There are two categories of LIFA ARCTIC referred to as THERMAL and PROWOOL. THERMAL is 100% polypropylene and is lightly brushed on the inside lifting the fabric from the skin, creating dead spaces which the manufacturer claims improves insulation. It is a dense knit, loose fitting garment for cold weather or less active work environments. It weighs 5.9 - 6.0 oz/sq yd. PROWOOL is 45% polypropylene/ 55% polyester/superwash wool and knitted so that the inside is 100% polypropylene and the outside is 70/30 polyester/superwash wool. It is designed for high energy and /or cold weather use. LIFA ACTIVE is designed to be worn as underwear or everyday leisurewear - since it is available in Europe only - it will not be discussed. There is a fourth line-- LIFA FLAME -RETARDANT-- which is made of 505 superwash treated and flame-retardant wool and 505 flame-retardant viscose.

Alpha® Olefin (staple)and Innova® Polyolefin (filament)are polypropylene yarns made by Amoco Fabrics and Fibers Co. Like all polypropylenes they are quick drying (absorb no moisture), transfer moisture in the vapor stage before it condenses on the skin, are wrinkle resistant, have low shrinkage, have low thermal conductivity (good insulator), are abrasion resistant, and

inherently resist bacteria growth and damage from perspiration.

Nylon:

Several underwear layers are nylon. Hydrofil nylon is the first commercially available absorbent nylon fiber by Allied Signal Inc. It is a patented hydrophilic fiber preventing vapor condensation allowing the fabric to breathe like a natural fiber and, at the same time, distribute moisture throughout the fabric surface to enhance evaporation. The manufacturer claims that Hydrofil nylon has the same strength, durability, ease of care and styling versatility as standard nylon, Hydrofil nylon's comfort properties are permanent, it is a completely new nylon block co-polymer; comfort is not dependent on the fiber shape or a finish. Hydrofil nylon handles high moisture vapor, making the fabric stay drier and comfortable according to the manufacturer. The manufacturer also claims the fibers can hold about 15% of their weight in moisture without feeling damp (the traditional nylon holds about 7%, polyester holds less than 1%). Hydrofil nylon can be machine washed and dried, is mildew resistant and will not degrade with moisture or perspiration. Body oils, stains and odors easily wash out of Hydrofil fabrics, and it produces less static electricity than traditional nylon or polyester. For thermal underwear and activewear, bi-component textiles using Hydrofil nylon are designed to utilize the "push/pull" moisture control concept. These fabrics have a hydrophobic fiber next to the body and Hydrofil nylon on the outside. Supposedly, the body pushes moisture from the skin and Hydrofil nylon pulls it away allowing the inside to stay soft and dry. Hydrofil nylon can be blended with a wide variety of natural and manmade fibers in knit, woven and nonwoven constructions. Underwear products using Hydrofil nylon are Drylete® by Hind and Transport MT3. Transport MT3 was tested by the Navy [1]. This product consists of polypropylene/Hydrofil nylon/and Lycra. The material tested weighed 9.18 oz/sq yd. Although thicker and heavier than the Polarmax(Thermax) tested, it exhibited comparable dry clo and moisture vapor permeability properties (see Table 5).

Drylete is a tri-component fabric developed by Hind sportswear and Allied Fibers. This tri-component stretch fabric is a combination of hydrophobic polyester next to the skin, Hydrofil nylon on the outside to disperse the sweat and Lycra to increase stretch and recovery for comfort and fit. There are three weights of Drylete available. Regular Drylete is 6.7 oz/sq yd, a lighter weight version, Lightweight Drylete® weighs 5.4 oz/sq yd and Arctic Drylete™ (Drylete with a polyester inner fleeced layer) weighs 8.2 oz/sq yd. According to Hind, when one works out, the body automatically generates heat toward the polyester layer. But polyester will not absorb sweat, so it pushes the sweat out to the Hydrofil, where it spreads out and evaporates, keeping the wearer dry. Regular Drylete can be worn in temperatures ranging from 0° to 100 °F , as a base layer or

alone. Lightweight Drylete can be worn as a base layer or alone in temperature ranges from 30° to 70° F. Arctic Drylete can be worn in temperatures ranging from -5° to 40 °F, as a base layer or alone. Arctic Drylete is wind resistant due to the tight knit construction.

Akwadyne by Comfort Technologies is a process used to molecularly modify nylon, giving it the same characteristics as polyester treated Akwatek (see Akwatek under polyester). Terramar® has developed a clothing system called Transport EC2™ which uses a fabric called EC2 Nylon™. Electrostatic Comfort Control (EC2) nylon is a fine denier nylon, permanently altered on a molecular level with a proprietary process (Akwadyne) that will never wash off or wear out. According to the manufacturer, EC2 nylon works the following way: negatively-charged particles in the EC2 nylon attack water's natural cohesion. These negative particles attract the positive water particles counteracting the forces holding water molecules together. An electrostatic process occurs whereby liquid water droplets are broken down into individual molecules that readily escape from the fabric. According to Terramar, evaporation takes place so rapidly that EC2 dries three times faster than a typical wicking fabric.

The Transport EC2 clothing system by Terramar is composed of four layers, the outer layers stand alone while the underlayers are not intended to stand alone. The first layer is the Stretch mesh which is engineered to maximize breathability and control heat and moisture levels. The fabric is a 3.9 oz,four way stretch mesh of EC2 nylon with 7% spandex and solid panels of a 5 oz 4-way stretch EC2 nylon with 7% spandex. This is a low bulk foundation layer designed to be worn under snug fitting layers but not alone. The second layer is called Lightning which is designed for layering over the stretch mesh. This lighweight, low-bulk combination provides a way to manage heat and moisture produced by aerobic sports in cold weather. The fabric is a 5 oz jersey knit with a 4 way stretch made of EC2 nylon and 7% spandex. Lightning when worn with the stretch mesh underneath can withstand temperatures between 50° to 35° F. Adding a wind suit can provide protection from 40° to 20 ° F. Universal, the third layer, is a fleeced insulation layer made of a 7 oz. four way stretch jersey knit EC2 nylon with 10% Spandex. Alone it can provide protection in the 60° to 40°F temperature range, with the mesh layer 40° to 25° F and with the mesh layer and windsuit 30° to 10° F. The outer layer, called Extreme, is designed for outdoor use in colder weather as a stand-alone layer. It is a single faced knit fleece fabric reinforced with Cordura™ and is used for climbing, mountain biking, backpacking and camping. The fabric is a 9.5 oz 4-way stretch knit made of EC2 nylon with Cordura, 8% spandex and fleeced inside for additional insulation. If used by itself, Extreme can protect against temperatures between 45° to 30° F. If combined with the mesh layer, it can protect in temperature ranges between 30° to 10° F and if the

windsuit is added from 20° to -5° F.

Other:

Fieldsensor™ is available in a mesh or knit construction and is made by Toray Industries, Inc., a Japanese firm. (Toray has a branch in New York but all of its fabrics are made in Japan.) Fieldsensor is a unique multi-layer structure whereby sweat is quickly absorbed by the inner fabric layer, the liquid is dispersed through a synthetic fabric layer and transported by the capillary action of the inner-fiber spaces to the outer surface. The liquid is dispersed through the fabric's outer layer, so that once it reaches the outer surface, it evaporates quickly keeping the inner layer sweat free, and comfortable to the skin.

Hoechst Celanese makes a cellulose acetate fiber called MicroSafe AM™ (antimicrobial) which can be used in underwear. It is an absorbent fiber that is permanently impregnated with an EPA registered antimicrobial additive called Microban. This additive defends against the growth of a broad range of bacteria, mold, mildew, fungus and yeast. Microban also controls bacteria-related odor and stains, thus creating more hygienic and comfortable conditions. The fiber can be blended to be washable. Protection reportedly lasts for the life of the product.

Extra Stretch Performance (ESP) another fiber by Hoechst Celanese, is a polyester yarn engineered to have stretch and recovery properties. It can be blended into underwear layers or fiberpile layers. This fiber gently follows body motion without binding, making it ideal for fashion sportswear and active wear. According to manufacturer claims, it can stand up to chlorine bleach, salt water, will not fade from exposure to sunlight, and its stretch and recovery performance improves with repeated washings.

Teijen makes a polyvinyl chloride underwear fabric called Teviron® III which has a brushed face and nylon back. No other data is available on this fabric at this time.

In terms of suitable FR underwear fabrics, the military currently uses a Nomex waffle weave knit fabric. In a recently published report, the Naval Air Warfare Center Aircraft Division in Warminster, PA conducted mannikin tests to determine if there were other materials readily available on the market that could replace the Nomex underwear currently being used, while providing comparable flame and thermal protection.[3] The ECWCS underwear was included in this study due to numerous requests for permission to use this item. Data showed the knit structure influenced the thermal properties more than the fiber type and no significant differences were noted in the im/clo values between the fabrics tested (See Table 5). On the Thermoman, four materials provided greater flame protection than the standard

Nomex: 1) the ECWCS polypropylene sample, 2) the Wool/Thermax sample, 3)the Capilene expedition weight sample, and 4) the Nomex/Thermax sample. The flammability results (like the thermal properties) were influenced more by the fabric thickness than the fiber type; however, this data may be misleading as the effect of melting into the skin is not measured. The ECWCS underwear did exhibit significant melting. The Capilene also exhibited melting, but on the outer rather than inner(skin)surface of the garment. The wool/Thermax sample did not exhibit signifigant melting but did char, and the Nomex/Thermax blend tested well. Based on this test data, the Wool/Thermax and Capilene expedition wgt were approved for use by Navy and Marine Corps Aircrews. Additional Nomex/Thermax blends, using different fiber deniers (1 dpf nomex) and knit structures will be investigated by the Navy for potential solutions to the thermal/flammability/comfort issue of the aircrew configuration.

Table 5. Mannikin Test Data on Underwear Fabrics

Sample	Thickness (in.)	Weight (oz/sq yd)	Clo	Im	Im/ Clo
Filament Silk	0.01	2.75	1.16	0.33	0.28
Spun Silk	0.02	4.02	1.24	0.35	0.28
Capilene lgt wt.	0.03	5.18	1.24	0.35	0.28
Polarmax (Thermax)	0.04	5.38	1.32	0.36	0.27
Capilene Mid wt.	0.04	6.02	1.29	0.33	0.26
Transport	0.07	9.18	1.28	0.35	0.27
Silk/Wool, exp wt.	0.08	4.66	1.47	0.34	0.23
Nomex/Thermax	0.08	7.03	1.47	0.34	0.23
Std Nomex	0.1	8.24	1.34	0.35	0.26
Wool/Thermax, exp wt	0.11	10.3	1.35	0.35	0.26
ECWCS Polypro	0.11	7.11	1.48	0.36	0.24
Capilene exp wt	0.17	7.51	1.56	0.39	0.25

Navy Test Data[3]

Layer 2: Pile Knit

The second layer of the ECWCS system is the fiberpile shirt and bib overalls. The material requirements for this item can be found in Cloth, Pile, Synthetic Pile (A-A-52107). It is a polyester staple fiber pile knit with a polyester backing (brown). It has a minimum weight of 11.0 oz/sq yd with an acrylic type resin applied to the non-pile side of the cloth to act as a binder or anti-curl agent (see Table 6).

Table 6. Layer 2: Pile Knit - Standard Requirements

Characteristic	Requirement	Test Method
Weight (oz/sq yd)	11	FED TM 5041
Bursting Strength (lbs)	170	FED TM 5120
Shrinkage (%)	5 (max)	FED TM 5580 or 5556
Elongation (%)	1 (max)	FED TM 5556 (wool procedure)
Colorfastness to:		
Laundering	good	FED TM 5610
Perspiration	good	FED TM 5680
Crocking	3.5	FED TM 5651
Dry cleaning	good	FED TM 5622

Pile fabrics have always been recognized as highly abrasion resistant, easy to care for, comfortable and fine insulators.

As mentioned, Polartec fabrics from Malden Mills Industries encompass a variety of different fabrics ranging in weight and construction designed for a range of activities (see Table 4). Polartec fabrics are knitted polyester or polyester blended fabrics reported to be quick drying and won't absorb water, keep their loft and insulate. The thermal mid-layer products- Polartec Series 200 - are available with or without a durable water repellent (DWR) finish. The Polartec series 300 can be worn as a thermal layer or outergarment. They are knit to allow the movement of air, thus allowing moisture vapor to escape. Polartec Power Stretch series - a breathable velour pile with Lycra body hugging four-way stretch for freedom of movement allows water movement and body moisture vapor to pass through the fabric while the thermal inner surface is fast wicking. The Polartec Recycled series available in series, 200, and 300 are made from a blend of 89% post consumer polyester and virgin polyester. According to Malden Mills, BiPolar Technology is the ultimate in moisture management. Bipolar uses different yarns,

different knit constructions and different chemical treatments or finishing techniques on each side of the fabric. The first layer wicks moisture away, making the mid-layer warmer and resistant to pilling. The outer layer is windproof and breathable. Table 4 details styles, descriptions and test results provided by Malden Mills. Polartec has an FR series which will be tested when samples become available.

Lowe Alpine Aleutian comes in a fleece style. The fabric is engineered with a microfleece outer face to deflect wind, shed rain and snow and resist pilling. The inside is lined with a brushed fleece for warmth.

WORKPILE is Helly Hansen's line of pile fabric. According to the manufacturer, it absorbs little moisture and lets through surplus heat. It is available in polyester, nylon and acrylic. The WORKPILE fabrics are made using a Fibrelock technique that is patented by Helly Hansen. This technique binds the pile to the ground yarn in a "W" structure (as opposed to the standard "V" structure), and Hansen claims it makes the pile very durable. It comes in a single sided or double sided version. The single sided version is made of polyester filaments designed to be used as an insulation layer in a three layer concept. It has a brushed inside face for loft and a tight knit outside for layering. It weighs approximately 12.1 oz/sq yd. The double sided version is made of nylon fibers and provides better insulation properties than the single-sided version. It is designed to be worn as an outer garment. A flame retardant WORKPILE is available. It is made of superwash wool and made flame retardant through a special process. This is machine washable. Helly Hansen also makes PROPILE, a lightweight layering garment. It is a double sided fabric made of 100% polyester, with a brushed inside surface and a sheared face. It weighs 8.85 oz/sq yd. This is also made using a "W knit" construction which the manufacturer claims insulates the body from the cold by trapping body heat in its fibers.

Borg textiles makes Zendura™, a line of pile fabrics with different finishes. Whether 100% polyester or a polyester blend, all Zendura products have the following characteristics: durability, warmth without weight, water resistance, wickability (wicks moisture away from the skin), breathability, quick drying, hypoallergenic, durable and resistant to pilling, quiet, odor resistant, and soft. Zendura contains one of the following finishes: Europa, Cascade, Norse, or Alpine which change the surface appearance of the fabric and is available in Zendura Recycled which uses Wellman's Fortrel Ecospun polyester fiber, Micro-Zendura, Zendura Fleeced (a brushed backing), and Zendura/Windbrake® which consists of Zendura fleece, a windproof/breathable membrane (Windbrake by Harrison Technologies) and a polyester mesh fabric next to the skin.

Table 7 shows test results of Zendura and a competitor obtained by Borg. All the Zendura fabrics in Table 7 weigh 12.0 oz/sq yd. The weights of the competitor fabrics are not specified.

Table 7. Zendura vs. Competitor

	Zendura (Europa Finish)	**Micro Zendura (Europa Finish)**	**Zendura (Cascade Finish)**	**Zendura Fleece (Europa Finish)**	**Series 200**	**Series 300**
Fiber Content	90% Polyester 10% Acrylic	100% Polyester	81% Polyester 11% Modacrylic 8% Acrylic	90% Polyester 10% Acrylic		
Colorfastness						
Crocking	5	5	5	5	5	5
Burst Strength (lbs/sq in)	230	250+	210	170	95	76
Flammability	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
Moisture Vapor Transmission ASTME96-93 Mehtod B	1044	1319	1175	1585	990	875
Air Permeability	229	234	333	275	247	215
CLO value	1.41	1.49	1.19	1.39	1.2	1.3

Manufacturer Data

Aqua Fleece Laminate by Descente is a 100% polyester fleece using a revolutionary unique "dot" laminate membrane to make it waterproof, windproof, and breathable. Water passes through the fabric, and surface water shakes off the garment.

Dyesburg Fabrics makes a line of polar "low-pilling" fleece fabrics which are both single and double sided. Weights range from lightweight microdeniers to expedition weight. The fabrics are made with Wellman's Fortrel Spunnaire® polyester. The Dyersburg E.C.O. Collection are double faced pile fabrics made with Wellman's Fortrel Ecospun which is 89% post-consumer recycled polyester.

Layer 3: Field Liner Coat and Trousers

The third layer of the ECWCS is the field liner trouser and coat liners. The insulation in this layer is a 4.4 oz/sq yd polyester batting quilted to a ripstop nylon fabric using a dumbbell quilt pattern. The requirements for the polyester batting component and test methods are listed in Table 8.

Table 8. Layer 3: Polyester Batting (Unquilted) Requirements

Characteristic	Requirement	Test Method
Weight (oz/sq yd)	4.4 + /- 0.4	FED TM 5041 (6 - 12x12"samples)
Thickness (in.) 0.01 psi		MIL-B-41826
Initial	0.49	
After Laundering	0.42	
Desired Clo Value		ASTM C 518 (95/55 F)
Initial	2	
After Laundering	1.8	
Compressional Recovery (%)	80 (min)	MIL-B-41826

There are many polyester batting materials on the market which can provide equal to or better thermal properties than the standard batting (MIL-B-41826) before laundering. However, one of the biggest obstacles that a batting for military applications must overcome is maintaining its performance characteristics and thermal properties after field laundering. There are a variety of battings, both staple and continuous filament, developed for a variety of end use applications. Some use staple fibers others continuous filaments, some binder fibers in lieu of resins to make them softer and give them better compression recovery. Some use microdenier fibers to provide more thermal efficiency, more loft and lighter weights and some are designed to be water repellent. The database that currently exists on non FR batting materials is included in Tables 9-11. One batting not included in the database is Exceloft by MontBell. Exceloft™ is composed of 0.8 denier polyester microfibers and 8 denier hollow tube fibers held together by a 3D heat crimping process. Siliconized fibers make the polyester fibers waterproof. According to manufacturer test data, it is 5% more efficient than Primaloft™, retains 80% of its insulation when wet and maintains 90% of its loft after 200 compression cycles. Samples of this batting should be obtained for testing. Two of the newest insulations on the market, both made of continuous filaments by Hoechst Celanese, are Polarguard HV and Polarguard 3D. PolarGuard HV (high void) has been type classified in the Modular Sleep System. It claims to have a 22% void which makes the resulting material lighter in

weight. Polarguard 3D uses a finer denier yarn than the Polarguard HV (3.5 vs 5.5), while maintaining the same void size. According to manufacturer claims Polarguard 3D has all the advantages of Polarguard HV (lighter weight) plus it provides improved thermal properties over Polarguard HV because of its finer denier yarns - Hoechst Celanese considers this their premium insulation. (Material data is not available on this insulation at this time, but material has been obtained for testing.)

Table 9 contains all the midweight battings that may be of consideration. Note all of these battings would be more expensive than the standard MIL-B-41826. The compositions of the battings listed can be found below:

Staple battings

MIL-B-41826, Class 9, hollow, 5.25-6.0 denier polyester fibers with 12- 18 % void in fiber. Resin. WR (water repellent) treated.

Primaloft 100% polyester a mixture of 85% 0.5 and 15% 4.0 denier polyester fibers. No resins /binder fibers use. WR treated

Liteloft 77% polyester/23% polyolefin (microdenier polyolefin fibers). Binder fibers used.

Microloft 100% polyester - 82% 0.7 denier polyester fibers and 18% 4.0 denier sheath core polyester fibers. Resin.

Continuous Filament

Polarguard 4.0 -6.0 denier polyester filaments. Resin.
Polarguard HV 5.5 denier hollow fiber with a 22% void. Resin.

Table 10 lists the lightweight battings available on the market. These battings are considerably lighter in weight than what is currently used in the field coat and trouser liner and provide lower clo values. The compositions of these battings are listed below:

Staple Bonded Battings

MIL-B-41826 Class 6 4.0-6.0 denier polyester fibers.
Liteloft 77% polyester 23% polyolefin

Table 11 lists battings of various weights and thicknesses that have been evaluated at Natick for various applications. These battings have limited interest to Natick for particular end item applications and would not be considered candidates for replacement of the current batting being used in the field liners for performance and/or price reasons. The compositions of these battings are listed below:

Staple bonded Battings
Thermolite

(Govt) 75% 1.65 denier polyester(37.5% coated/37.5% uncoated)
25% 4.0 Denier polyester

(Com) 82% 1.65 denier polyester (55% coated/27% uncoated)
18% 4.0 denier polyester

Thinsulate 65% polyolefin microfibers(0.4-7.3 microns ave 1.0-3.0)
35% 12-14 denier polyester staple fibers

Table 9. Properties of Midweight Battings (Unquilted)

Material	Thickness (in) 0.002 psi	Bulk Density (lb/cu ft)	Weight (oz/sq yd)	Clo Intrin-sic	Clo/ oz/sq yd	Compression Recovery (%) *
MIL-B-41826, Class9						
Original	0.94	0.37	4.2	2.1	0.5	80 (min)
Laundered	0.61	0.61	4.5	1.9	0.42	80 (min)
Primaloft						
Original	0.81	0.44	4.27	3.78	0.88	86.4
Laundered	0.29	1.23	4.34	1.68	0.39	
Liteloft 96g/sq m						
Original	0.98	0.27	2.96	2.65	0.9	92.9
Laundered	0.34	0.79	3.19	1.37	0.43	91.3
Microloft 150 R						
Original	0.62	0.59	4.38	2.72	0.62	91.3
Laundered	0.24	1.65	4.69	1.23	0.26	91.5
Polarguard-E32 resin						
Original	0.86	0.44	4.48	1.67	0.37	86.5
Laundered	0.61	0.64	4.71	1.59	0.34	85.5
Polarguard HV (4.4 oz)						
Original	0.99	0.31	3.6	1.79	0.5	
Laundered	0.53	0.6	3.74	1.25	0.33	
Polarguard HV (3.6 oz)						
Original	0.9	0.32	3.43	1.57	0.46	
Laundered	0.43	0.68	3.56	1.15	0.32	

Natick Data
Average of 3 samples unless otherwise indicated

*Average of 6 samples
For test methods see Table 8

Table 10. Properties of Lightweight Battings (Unquilted)

	Thickness (in) 0.002 psi	Bulk Density (lb/cuft)	Weight (oz/sq yd)	Clo Intrinsic	Clo/ 0z/sq yd	Compression Recovery (%)*
Liteloft 65g/sq m						
Original	0.68	0.25	2.07	2.3	1.1	92
Laundered	0.18	1.08	2.21	0.79	0.36	87.9
MIL-B-41826, Class 6						
Original	0.49	0.32	1.9	1	0.53	80 (min)
Laundered	0.2	0.75	1.8	0.6	0.33	80(min)

Natick Data
Average of 3 samples unless indicated otherwise.
*Average of 6 samples.
For test methods see Table 8

In addition to the polyester/polyolefin blended battings, there are some FR battings available. Data on the Nomex batting which is currently being used for FR protection, as well as some FR battings developed for clothing applications (most of the FR insulations on the market were designed for non-apparel applications) can be seen in Table 12. None of these battings show a significant improvement over the Nomex batting currently being used. The compositions of these battings are listed below:

Staple Battings

Nomex MIL-B-81813 3.8-4.8 oz/sq yd 2 denier staple fiber. Needled

P84/Poly - 60% 1,5 denier P84,WR finish,
22% 0.55 denier P84 with WR finish
18% 4.0 denier polyester binder fiber

75%Curlon/25% polyester - Curlon approx 10 microns 1.5 inch
5.0 denier bi-component polyester binder

60% polyester/40% Curlon - 40% 0.7 denier 2inch polyester
20& 2.0 denier Cellbond bicomponent polyester binder
40% Curlon

Microlite AA and Acoustic AA - 0.3-2.0 micron (average 1.0 -1.2 micron) fiberglass fibers, Resin, WR

Pyroloft A 0.5 denier P84/4.0 denier high temperature polyester binder

Pyroloft C 2.0 denier P84/4.0 denier polyester binder

Pyroloft CA 5.0 Denier P84/4.0 denier polyester binder

Table 11. Batting Properties (Unquilted)

Material	Thickness (in) 0.002 psi	Bulk Density (lb/cu ft)	Weight (oz/sq yd)	Clo Intrinsic	Clo/ oz/sq yd	Compressional Recovery (%)
Thermolite						
GOVT - Original	0.69	1.11	9.13	3.04	0.33	93.9
Laundered	0.65	1.17	9.19	2.76	0.3	91.7
COM - Original	0.73	1.05	9.17	3.28	0.36	94
Laundered	0.74	1.07	9.47	3.1	0.33	91.6
Thermolite T-O	0.46	0.97	5.4	1.85	0.34	
	0.45	1.45	7.7	1.92	0.25	
	0.81	0.9	8.8	3.06	0.35	
T-18	0.47	1.03	5.8	1.72	0.3	
Thermolite,100 g/sq m						
Original	0.3	0.83	2.97	1.18	0.4	
Laundered						
Thinsulate						
CS 100 g/sq m						
Original	0.35	0.89	3.7	1.5	0.4	
Laundered	0.2	1.65	4.1	1.1	0.27	
CS 150 g/sq m						
Original	0.43	1.05	5.4	2	0.37	
Laundered	0.3	1.63	5.8	1.4	0.25	
CS 200 g/sq m						
Original	0.55	1.03	6.8	2.3	0.34	
Laundered	0.41	1.63	8	2	0.25	
CS 250 g/sq m						
Original	0.67	1.05	8.5	2.8	0.33	
CS 300 g/sq m						
Original	0.81	1.06	10.4	3.4	0.33	
Laundered	0.58	1.73	12.1	2.6	0.21	

Average of 3 samples unless indicated otherwise.
Note: Average of 6 samples used in compression testing.
For test methods see Table 8

Table 12. Flame-Reisistant Battings

	Thickness (in) 0.002 psi	Bulk Density (lb/cu ft)	Weight (oz/sq yd)	Clo Intrin-sic	Compression Recovery(%)	Flamm-ability
Nomex	(unquilted)					
Unlaundered *	0.29	1.28	4.46	1.34		
Laundered*	0.23	1.36	3.65	1.11		
Nomex	(quilting removed)					
Unlaundered	0.27	1.31	4.25	1.33	***85.1	pass
Laundered	0.2	1.82	4.35	1.12	***88.6	pass
P84/poly blend						
Unlaundered	0.89	0.35	3.71	3.63	***89.1	fail
Laundered	0.5	0.62	3.73	2.42	***91	fail
60% Poly/40% EDF						
Unlaundered	0.59	0.59	4.17	2.61	***89.6	pass
Laundered	0.26	1.42	4.37	1.1	***87.6	fail
75%Curlon/25%Poly	(quilting removed)					
Unlaundered	0.88	0.67	7.03	4.41	***95.3	pass
Laundered	0.58	0.99	6.87	3.13	**92.9	pass
Microlite AA						
Unlaundered	***1.03	***0.57	***7.0	4.63	***87.3	pass
						pass
Acoustic AA						
Unlaundered	***0.9	***0.4	***4.34	3.57	***77.8	
Pyroloft A*						
Unlaundered	0.66	0.42	3.31	4.21		pass
Laundered	0.45	0.64	3.47	2.72		pass
Pyroloft C*						
Unlaundered	0.39	0.34	1.6	1.89		pass
Laundered	0.23	0.59	1.63	1.02		pass
Pyroloft CA*						
Unlaundered	0.86	0.73	7.4	3.41		pass
Laundered	0.69	0.97	8.05	2.99		pass
72%Curlon/28%Poly						
Unlaundered	0.17	1.87	3.82	1		pass

Natick Data[4]	*** Average of 6 samples ** Average of 5 samples * Average of 2 samples Average of 3 samples unless otherwise indicated

For test methods see Table 8

In the category of "smart materials", Gateway Technologies is marketing a phase change material under the trademark Outlast™. This involves the topical application of coatings containing microencapsulated materials (2.5 oz/sq yd)or incorporation of the microencapsulated phase change (MEPC) materials into the polymer. To date, MEPC materials have only been incorporated into acrylic resulting in a 10% weight reduction of the fiber. Polypropylene with MEPC materials are expected to be available by the summer of 1996 and polyester and nylon within two to three years. Phase change materials work the following way: heat from the body, or any heat source, causes the microencapsulated material to change phases at a molecular level over a broad range of temperatures. When the materials change phase, heat energy is absorbed or emitted in selected temperature ranges. Therefore, the fabric can be used to achieve an insulating or cooling effect depending on body and environmental conditions. According to manufacturer data, Outlast fabrics have been proven by an independent laboratory to be warmer significantly longer than lofted insulation. It is 375% warmer than lofted insulations which are 3 times thicker and 425% warmer than lofted insulation of nearly equal thickness. The Outlast coating can be applied to any synthetic or natural fabric to enhance its thermal capacity. It is designed to deliver more warmth for longer times while adding only a few thousandths of an inch to the base fabric. The manufacturer claims Outlast has the unique ability to efficiently retain heat and distribute it uniformly within the fabric. Fabrics are not affected by washing or dry cleaning. The cost of the MEPC is currently $30/lb, but is expected to drop to $10/lb within 2 years. While this material seems promising, the dynamic testing required to measure the performance of these materials under varying temperature ranges is not currently available to determine the potential of this concept for military applications.

Layer 4: Waterproof, Moisture Vapor Permeable Laminated Cloth

The fourth layer of the ECWCS is a waterproof, moisture vapor permeable laminated cloth. The ECWCS system currently uses a three-layered laminate Cloth, Laminated, Waterproof and Moisture Vapor Permeable (MIL-C-44187). This system uses a nylon cloth 2.8± 0.2 oz/sq yd in a woodland camouflage pattern, a plastic film, made of polytetrafluorethylene film weighing 0.5± 0.2 oz/sq yd or a polyolefin microporous membrane fully saturated with a hydrophilic urethane and a nylon tricot knit 1.5 ±0.3 oz/sq yd. The maximum weight of the laminate is 5.9 oz/sq yd. The requirements that are required of a replacement material can be found in the Appendix.

Shell Fabrics

Fibers from DuPont® can be used in any layers from the active bodywear to the waterproof parka layer, depending on what they are blended with and how they are constructed (knit or woven). Supplex® is made of finer denier fibers than ordinary nylon fibers (1.0 dpf vs. 2.0 dpf)which the manufacturer claims contributes to a softer cotton-like hand (26 - 36% softer than regular nylon fabrics), lighter weight, reduced bulk, greater breaking and bursting strengths and higher abrasion resistance. Both Supplex® and Tactel®, fibers are very similar in nature and are versatile enough for all types of weather and all types of activities. In outerwear they are strong and resist abrasion, punctures and tears. When blended with Lyrca®, (another DuPont fiber) they provide gentle support, great fit and freedom of movement. Supplex® and Tactel® according to manufacturer claims, are quick-drying, breathable fabrics that do not absorb or retain moisture and let moisture escape through the fabric. They are also shrink resistant, fade resistant, and can be machine washed and dried.

MicroSupplex™ is the newest member of the DuPont® Sports Products group. The manufacturer claims it is lightweight, breathable and comfortable. It is a microdenier nylon (0.7 dpf) that is said to be finer than silk and results in fabrics that are soft. Due to the tighter weave of MicroSupplex™, the fabrics are two times more wind resistant and 10% better than standard nylon at repelling water. According to DuPont®, MicroSupplex™ outperforms nylon taffeta and poly/cotton in strength and abrasion tests.

Micromattique™, another DuPont® fiber, is a microdenier (0.5 dpf) solid polyester used in higher end active wear and outerwear. The microfibers provide greater flexibility in the fabric appearance, it can be "feather weight", or firm (such as a

suiting fabric) with an ultra-soft hand. Micromattique™ can be woven or knitted, used alone or blended with other fibers such as cotton, wool or Lycra®.

Toray manufactures two fabrics which can be used as an outer shell called H_2OFF™, and Chamistie. H_2OFF achieves water repellency through a fabric structure called "water shed architecture" which uses an ultra-dense weave with millions of microcrimped fiber loops (100% polyester). The air trapped among the loops form a natural buffer making it inherently water repellent while microporous air channels in the fabric let moisture pass freely to the outside providing breathability. H_2OFF is also windproof. According to Toray, H_2OFF has better water repellency (using test method ASTM-D-583) than other moisture-permeable rainwear. H_2OFF also provides a high resistance to water penetration without the use of coatings or laminates, promoting breathability and comfort. According to test method ASTM-D-751B, the fabric withstood up to 500 mm or more of hydrostatic pressure which means that H_2OFF effectively maintains dryness even under very wet conditions. H_2OFF releases up to 900 g/m^2 of moisture within 24 hours (according to ASTM-E-96-66E). It can be hand or machine washed in warm water (no bleach), and tumble dried using a medium setting. If the fabric needs to be ironed, the heat has to be kept at less than 120°C.

Triviera Fineese® is a 100% polyester microfiber (0.55 -0.7 dpf)by Hoechst Celanese. Fabrics woven using these microfibers claim to have a high density; therefore, the "pores" are small enough to bar wind and rain, yet large enough to allow body moisture to evaporate without using coatings, membranes, or films, making it a lightweight single layer fabric.

Films/Laminates

Harrison Technologies has two waterproof and moisture vapor permeable products, TRIAD® and WindBreak™. TRIAD, a waterproof breathable/windproof film, is based on a monolithic hydrophilic polyurethane copolymer named Vapex™. It is made by Enterprise Coatings. Harrison Technologies supplies TRIAD to the manufacturer in three principal ways : 1) laminated to the customer's fabric, 2) on various substrates and fabrics or 3) as a heat sealed finished insert and liner. The features of TRIAD as stated in the literature include the following, it is waterproof, has high breathability, is windproof, is non-particulating, has good seam strength, good tensile strength, is heat sealable, non-yellowing, washable and dry cleanable and is stretchable. Table 13 provides test results submitted by Harrison Technologies.

Table 13. TRIAD Laminated to 40 Denier Nylon Tricot

Seam Seal Strength	3.6 lbs./in.
Waterproofness (Mullen)	
Film Down - Initial	84 psi
- After 1000 cycles Abrasion	84 psi
Tear Strength-Elmendorf Method	warp - 2,544 gms.
	filling - 928 gms
Tensile Strength	warp - 7.1 lbs.
	filling - 3.6 lbs.
Moisture Vapor Transmission Rate ASTM E 96 Method Upright Cup	1.135gms/sqm/24 hrs.

Manufacturer Data
Tested according to Fed Std 191A unless otherwise specified.

Windbreak is a windproof/breathable technology created through a joint effort between Enterprise Coatings Co. LTD and Harrison Technologies Inc. based on Enterprise's Vapex/TRIAD waterproof/breathable technology. Using a coating and laminating process, any combination of knit to knit, woven to woven, or woven to knit can be accomplished. Windbreak is sandwiched between a jersey knit on the outside and a fleeced fabric on the inside making it windproof. This is part of Borg's Zendura product line. Table 14 shows test results obtained from Harrison Technologies comparing a regular sweatshirt fleece with the Windbreak sweatshirt fleece. Windbreak can be incorporated into any Zendura fabric, finish pattern or color, and the manufacturer claims it is not stiff or noisy.

Table 14. Windbrake Sweatshirt Vs. Regular Sweatshirt

	Windbrake	Regular
Wind Penetration	less than 1 CFM	200+ CFM
Breathability		
MVTR ASTM/E96 80	1800gms/sqm/24 hrs.	3000 gms/sq m/24 hrs.
Added Weight	0.75 oz/sq yd	

Manufacturer Data

The waterproof breathable system from Hind is called RegulatAire™. It is a "shape memory polymer coating" applied to

a 2-layer polyester microfiber face fabric weighing 5.0 oz/sq yd. This memory shape polymer reacts to body temperature by expanding and allowing moisture vapor to pass through fabric during high aerobic activity and closes when cold temperatures reduce body heat keeping heat in to maintain the core body temperature. RegulatAire is windproof and waterproof, claims to have a soft hand and is lightweight. The MVTR is rated as excellent, it has a softer hand than Goretex - which tends to be noisy and stiff - and has a durable water repellent finish according to the data supplied by the manufacturer. RegulatAire is compared to Goretex in Table 15. This data was supplied by Hind.

Table 15. RegulatAire Vs Competitors

	RegulatAire	Goretex
Construction	2 Layer/Micropoly	2 layer/Supplex nylon
Hand	soft	noisy/can be stiff
MVTR	747 gms	614 gms
Water Repellency	Excellent	Average
Water Proofness	35 psi	60 psi

Manufacturer Data

Entrant GII™ made by Toray, is a proprietary three-layer waterproof, moisture permeable coating added to a base fabric (nylon or polyester) which has a durable water repellent finish. The first layer prevents water penetration and provides cohesion (preventing the coating from peeling off). It contains minuscule pores that measure less than 0.5 um in diameter. The second layer is a hybrid foam layer containing 0.5 um pores as well as slightly larger pores. The manufacturer claims this hybrid configuration provides moisture permeability and resistance to water penetration. The third layer (or inner most layer) strengthens the coatings surface and inhibits dew condensation. It has small pores that measure less than 1um in diameter and a fine, uneven resin surface. When tested on the Mullen tester, Entrant GII maintains resistance to hydraulic pressure, has little dew condensation, and exhibits lower vapor pressure (moisture level) when compared to a conventional waterproof fabric according to the manufacturer data listed in Table 16. Entrant GII comes in two types of fabrics. There is a Type P which has higher moisture permeability and water pressure resistance than Type C which is suited for general sport applications including skiing and golf. Both types (P&C) can be combined with nylon and polyester woven fabrics. The properties of Entrant GII supplied by the manufacturer can be found in Table 16.

Table 16. Entrant GII Performance Characteristics

Sample	Type P			Type C			Test Method
	LU890LH	S205LH	R720LH	LU890L	S205L	R720L	
Base fabric type	100% nylon cotton-like tafetta	100% nylon multifilament taffeta	100% polyester microfiber tafetta	100% nylon cotton-like tafetta	100% nylon multifilament taffeta	100% polyester microfiber tafetta	----------
Waterproofness (kg/sq cm)	2.0	2.4	2.5	0.6	0.75	0.70	JIS L 1092B
Moisture permeability (g/sq m*24hrs)	6100	6000	6300	9600	9400	10100	JIS L 1099 A-1 (ASTM-E-96-66E)
Water repellency (point)	L=0 90 or higher	90 or higher	90 or higher	90 or higher	90 or higher	90 or higher	ISO 4920 (JIS L 1092)
	L=20 80	80	80	80	80	80	

Manufacturer Data
L=0 : before laundering   L=20: after 20 washing cycles

Lowe Alpine Systems uses a waterproof moisture vapor permeable coating incorporating a layer of ceramic fibers called Triple Point Ceramic. The manufacturer claims it has breathability under rainfall, resistance to leakage under pressure, and resistance to condensation and wetting out after extended exposure to rainfall. In a much disputed test performed by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) Triple Point 1200 was rated higher in breathability than Gore-tex. Triple Point is available in 1200,1400 and 1600 weights with 1200 being the lightest.

Helly-Tech® by Helly Hansen uses a proprietary polyurethane coating process which prevents water from getting in and allows moisture to be forced out by combining multiple layers of a microporous coating containing millions of pores per sq cm (average size of 5 microns) and a hydrophilic coating which is a waterproof barrier containing hydrophilic molecular groups. There are three different types of breathable, waterproof systems. The Helly Tech Lightning Coating consists of 15% microporous and 85% hydrophilic coating allowing a high level of moisture vapor transmission and waterproofness (good in humid weather). The Helly Tech Classic Coating is made up of a 85% microporous and 15% hydrophilic coating providing the highest level of moisture transportation (designed for comfort). The Helly Tech Pro Coating is made of a 50% microporous and 50% hydrophilic coating designed to provide maximum protection.

Stedfast, a Canadian company, makes Stedair® a moisture vapor permeable membrane. According to literature, vapor movement occurs two ways - 1) a microporous membrane allowing

vapor to escape and making the membrane impermeable and 2) hydrophilic polyurethane groups guide water through the membrane towards the outside while blocking access to water.

Sympatex®, by Akzo Nobel, Netherlands - distributed by Brookwood Industries N.Y. - is a non-porous polyester membrane with hydrophilic (water attracting) zones which is laminated to a fabric. Sympatex stretchs up to 300% in any direction, is windproof, and extremely thin (10 Microns). Sympatex can be made into a two layer laminate, laminated to an outer fabric, lining, or to a fleece or knitted fabric and inserted between the outer fabric and the lining of a three layer laminate. According to manufacturer data, Sympatex has no pores to get clogged, is windproof (providing greater warmth), is breathable, has a high flex tolerance, and high abrasion resistance. A water repellent shell fabric is required in order to prevent the laminate from getting wet (and heavy) in the rain. Garments require special taping in order to withstand hydrostatic pressure. Sympatex now has a Windliner and Elastic program. The manufacturer claims Windliner is windproof and breathable, highly water resistant, soft, and quiet. It is used in knit wear, gloves and outerwear. The Sympatex Elastic program has all the same properties as the Sympatex membrane, but it can be stretched up to 500% and still recover without losing performance.

Table 17. Properties of Sympatex

Density	79.2 lb/cu ft
Thickness	0.4 mil
Weight	0.37 oz/sq yd
Elongation at break	300%+
Breathability	
ASTME96-66, method B	2700g/sq m 24 hr
ISO 11092	.017 sqm mbar/W
Moisture Absorption	1.6%@20 C And 50%
Water Absorption	Approx 5% at 20 C
Windproofness (DIN 53 887)	no wind passage

Manufacturer Data

Goretex®, a registered trademark of W.L.Gore & Associates, Inc., was introduced in 1976. It is used by Gore licensees to fabricate their own brands of waterproof, breathable, windproof products. The Goretex membrane is a composite of materials. The first component is pure expanded hydrophobic (water-hating) polytetrafluoroethylene (PTFE) which contains nine billion pores per sq in. These pores do not allow water to pass through the membrane, but do allow moisture vapor to pass through. The second component is polyalkylene oxide polyurethane -urea, an oil hating substance which prevents contamination of the Goretex membrane from oils, cosmetics, insect repellents, food substances, and other hazards. This membrane is laminated to a waterproof fabric and can withstand 65 psi water entry pressure according to a U.K. standard test method which Gore feels duplicates real world. Gore tests also claim Goretex has the lowest resistance to moisture vapor transfer making it more breathable than competitive products, Goretex has good wet flex and abrasion resistance, does well in cold flex tests and the Gore-Seam tape is 5 -16 times more flexible than others (all seams must be sealed with Gore-Seam tape), is permanently waterproof and has a water repellent finish applied to the outer fabric which must be reapplied over time. For maximum moisture vapor transport, the Goretex membrane should be worn close to the skin.

Windstopper™ membrane also by Gore, is more breathable than the Goretex membrane. It is windproof like Goretex, but not waterproof. Windstopper fabrics are not intended for use in wet weather, therefore seam sealing is not required. This fabric has three basic uses: windproof liners for sweaters, pants and casual wear, windproof fleece for outerwear (according to Gore, windproof fleeces provide 2 1/2 times the warmth of ordinary fleece and will not sacrifice breathability), and windproof shirts for aerobic sports and casual wear. These products minimize heat and moisture buildup during activity, while reducing the chilling effects of cold winds at high speeds.

Activent™ fabric by Gore is a monolithic microporous barrier technology which is breathable, water resistant and windproof. It is a different membrane and polymer than Gore-tex. A water repellent surface treatment is applied to the fabric but it is not permanent and wears off. The Activent barrier weighs only 0.5 oz/sq yd and is currently applied to a 1.4 oz/sq yd fabric. Activent fabrics can be laminated to different types of fabrics and weaves, offering a wider range of aesthetics. Activent is not air permeable, is not waterproof but water-resistant, offering comfortable protection for short durations outside.

Gore-tex™ Thermodry Plus in an insulation/membrane engineered for dry, lightweight warmth. It combats radiant heat loss, by using fine denier polyester fibers coated with a micro-

thin layer of highly reflective aluminum. Each fiber's aluminum surface acts like a reflective shield to reflect the body's radiant heat from fiber to fiber and back to the wearer of the garment. The Gore-tex membrane is laminated directly to the aluminum-coated insulation, so it is waterproof, windproof and breathable. The Gore-tex Thermodry Plus Layer is completely seam sealed and placed between the outer shell and inner lining.

Drytec™ by Montbell is a waterproof breathable coating available in a 2-layer or 3-layer configuration.

Hydropro by Montbell is a waterproof, polyurethane coating which utilizes ester bonding which chemically welds Hydropro to the fabric and bonds the seam tape to the coating.

MemBrain™ Smart Fabric made by Marmot™ is a microthin laminate made from polymers with strands of temperature-sensitive molecules that expand and contract (change shape) to adjust breathability of the garment to the activity level. This item, according to literature,is always performing at an optimum level - the polymer strand construction literally changes from closed when it's cold increasing heat retention, to open when it's warm to increase breathability. NATICK data is available on this membrane. However, the testing was done under static rather than dynamic test conditions. Therefore, the full potential of this material can not be realized.

The Polartec Winbloc series by Malden Mills is an outer layer containing a breathable membrane that transports moisture from the humid environment inside clothes to the outside. It protects against 40 mph winds and is waterproof. See Table 4 for Manufacturer details.

Discussions

While there are many candidates that may be suitable replacements for the current ECWCS layers, there are some which seem more appropriate than others.

For the underwear layer, the most important characteristic is that the fabric move moisture away from the skin so that the wearer stays dry. This can be achieved several different ways - fiber composition, fiber cross section, addition of a chemical or molecular process or finish, or fabric construction. Basically, the Navy's study shows the knit structure not the fiber to have the greatest impact on the moisture vapor permeability characteristics of the fabric. The less the moisture vapor resistance, the greater evaporative cooling during periods of increased activity - an important consideration for underwear fabrics.

While several of the underwear fabrics have been tested and evaluated, and could have potential military applications, the Terramar Transport EC2 clothing system seems to offer a low bulk alternative which may merit further investigation.

The pile layer is used for insulation. It appears that the Polartec line of fleeces may offer some improvement over the fleece currently being used in the ECWCS. In fact, a recently published report from the Navy indicates that in manikin testing, the Polartec Series 200 or 300 fleece cold weather underwear could be used to replace the standard cold weather underwear combination of the synthetic fiber pile cold weather shirt and the polypropylene cold weather trousers.[5] The Polartec Series 300 samples while adding slightly more weight (1.0 vs 1.3 kg) provided 13% higher im/clo ratios than the standard ECWCS layers tested meaning it could dissipate heat through the clothing system easier. Physical test data, launderability (dimensional stability), and guarded hot plate testing is being generated for a large portion of the Polartec line. Also of interest is the Dyersburg pile knit fabrics which claim to have a low-pill velour finish.

The third layer consists of a quilted insulated liner which uses a polyester batting. Improved insulations are available on the market; however, many of them do not perform well in military laundering or the cost increase can not be justified. Several options exist to improve this layer. It appears that the thrust in the commercial market is to eliminate the batting layers and replace them with pile/fleeced fabric. Both the Terramar and the Helly Hansen clothing systems use a combination of knit fabrics varying in weight and construction including pile/fleeced/brushed single and double sided knits for the insulation layer. The advantage to this is that it eliminates bulk. The disadvantage is that it tends to add weight. Fibrous insulative battings, while bulkier, tend to provide more insulation due to trapped air. In keeping with the modular concept and trying to eliminate as many layers as possible, the Gore-tex Thermodry Plus is an insulation/membrane configuration that may be of interest. Although this particular item has not been tested at Natick, aluminized fibers tested in battings at Natick have not exhibited any significant advantage over other battings. In fact, the sample tested (Ultrafibre) exhibited unsatisfactory durability of the aluminum coating in military laundering.[6] Microencapsulated phase change (MEPC) materials may be a way of decreasing bulk in the system. Incorporation of the MEPH materials into the polyester polymer should decrease the weight of the fiber based on what happened when it was added to the acrylic fiber. This technology is projected to be available in the next 2 -3 years and should be followed for possible military applications. Another possibility may be to investigate different construction techniques. Data suggests that a straight channel quilt yields higher thermal efficiencies than the

dumbbell quilt pattern currently being used.[4]

The most novel and intriguing technology that was uncovered in this literature search/market survey was the MemBrain Smart Fabric. This technology could incorporate the insulation layer into the fourth layer of the system, but it is a Japanese technology and may pose a problem. In terms of replacing the PTFE membrane currently in use, there are several membranes discussed. Some data has been generated on these membranes by the Special Systems Group. Also, several concepts were discussed which combined the fleece and membrane layer such as the Windbrake, Windstopper, Windliner and Aqua Fleece Laminate fabrics.

Conclusions

Several alternative materials have been identified for replacement of the current ECWCS. Physical and thermal testing is required before the suitability of the materials can be determined.

Recommendations

- Generate test data on promising candidates.
- Perform a cost analysis on most promising candidates.

This document reports research undertaken at the U.S. Army Soldier Systems Command, Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-98/006 in the series of reports approved for publication.

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As mentioned, much of the data and information on the products themselves were obtained from manufacturer generated data.

APPENDIX
2GECWCS MATERIAL REQUIREMENTS

Appendix A

2GECWCS MATERIAL REQUIREMENTS

CHARACTERISTICS	2GECWCS REQUIREMENTS	TEST METHODS
Weight	6.0 oz/sq yd max.	ASTM D 3776
Color	4 color Woodland Camouflage Pattern	Visual-match standard sample
Colorfastness to light	Equal to or better than "3-4" AATCC Gray Scale for Color Change rating after 40 hours.	AATCC #16, option "A"
Colorfastness to Laundering	Equal to or better than "3-4" AATCC Gray Scale for Color Change rating (4 cycles)	AATCC #61, option 1A & Army detergent
Colorfastness to accelerated laundering. (Black only)	Equal to or better than "3-4" on AATCC Gray Scale rating.	Test procedure "A"
Colorfastness to Crocking	4 Colors: Equal to or better than "3.5" AATCC Chromatic Transference Scale Rating.	AATCC #8
Pattern Execution	Equal to standard sample. Repeat on 27.25" +1.25", -2.5" warp.	Direct linear measure
Spectral Reflectance	See Table	Test procedure "B"
Breaking Strength (WxF)	Warp = 135 lbs, min. Filling = 100 lbs, min	ASTM D 5034
Tearing Strength (WxF)	W = 3.0 kgf, min F = 3.0 kgf, min	ASTM D #2582

Moisture Vapor Transmission Rate (MVTR). Cond 1 Proc. B & Proc BW Cond 2 Proc. B or Proc. BW	 600 g/m sq/24hrs, min 3600 g/m sq/24hrs, min 600 g/m sq/24hrs, min 3600 g/m sq/24hrs, min	 ASTM E 96, Procedure B 1/ & BW 2/ ASTM E 96, Procedure B 1/ & BW 2/
MVTR, after synthetic perspiration - Cond 1 Proc. B & Proc BW Cond 2 Proc. B & Proc BW	 600 g/m sq/24 hrs, min 3600 g/m sq/24hrs, min 600 g/m sq/24hrs, min 3600 g/m sq/24hrs, min	 Test procedure "C" & ASTM E 96, Procedure B 1/ & BW 2/ Test procedure "C" & ASTM E 96, Procedure B 1/ & BW 2/
Hydrostatic Resistance (HR) - Initial	No leakage (40 psi)	ASTM D 3393
HR, after strength of coating	No leakage (40 psi)	FED-STD-191 #5972 4/ & ASTM D 3393
HR, after abrasion, (face and back)	No leakage (40 psi)	AATCC #119 1/ & ASTM D 3393
HR, after exposure to DEET Initial exposure After Laundering	 No leakage (40 psi) No leakage (40 psi) (1 cycle)	 Test procedure "D" & ASTM D 3393 Test procedure "D" & "F" and ASTM D 3393

HR, after exposure to diesel Initial exposure After laundering	No leakage (40 psi) No leakage (40 psi) (1 cycle)	Test procedure "D" & ASTM D 3393 Test procedure "D" & "F" and ASTM D 3393
HR, after exposure to weapons lubricant Initial exposure After laundering	No leakage (40 psi) No leakage (40 psi) (1 cycle)	Test procedure "D" & ASTM D 3393 Test procedure "D" & "F" and ASTM D 3393
Hydrostatic Resistance after high humidity	No leakage (40 psi)	Test procedure "J" & ASTM D 3393
Stiffness	10.0 cm - maximum	FED-STD-191 #5204
Water Permeability Initial	No leakage (50 cm/10 minutes)	AATCC #127 6/
Water Permeability after flex, 70°F (warp & filling)	No leakage (50 cm/10 minutes)	Test procedure "G" & AATCC #127 6/
Water Permeability after synthetic perspiration Initial exposure After laundering	No leakage (50 cm/10 minutes) No leakage (50 cm/10 minutes) (1 cycle)	Test procedure "C" & AATCC #127 6/ Test procedure "C" & "F" and AATCC #127 6/
Water Permeability after cold flex, -40°F - Warp & Filling	No leakage (50 cm/10 minutes)	Test procedure "H" & AATCC #127 6/

Water Permeability after DEET Initial exposure After laundering	No leakage (50 cm/10 minutes) No leakage (50 cm/10 minutes) (1 cycle)	Test procedure "D" & AATCC #127 6/ Test procedure "D" & "F" and AATCC #127 6/
Water Permeability after diesel Initial exposure After laundering	No leakage (50 cm/10 minutes) No leakage (50 cm/10 minutes) (1 cycle)	Test procedure "D" & AATCC #127 6/ Test procedure "D" & "F" and AATCC #127 6/
WP, after weapons lubricant Initial exposure After laundering	No leakage (50 cm/10 minutes) No leakage (50 cm/10 minutes) (1 cycle)	Test procedure "D" & AATCC #127 6/ Test procedure "D" & "F" and AATCC #127 6/
Spray Rating After laundering	Equal to or better than 90,90,80 after 5 laundering	Test procedure "F" & AATCC #22
Resistance to Organic liquids After laundering	No wetting by n-tetradecane after 5 laundering	Test procedure "F" & AATCC #118
Physical Surface appearance changes after laundering	No changes in physical surface appearance after 20 laundering	Test procedure "E"
Dimensional Stability, Warp x Filling	Warp - 4.0% (max.) Filling - 2.0% (max.)	FED-STD-191 #5552

Water Permeability after Seam Tape	No leakage (50 cm/10 minutes)	Test procedure "K"

1/
The back side of the test cloth shall face the water, the free stream air velocity shall be 550 ± 50 FPM as measured 2 inches above the fabric specimen. The air flow shall be measured at least 2 inches from any other surface. The test shall be run for 24 hours and weight measurements shall be taken at only the start and completion of the test. At the start of the 24 hour test period, the air gap between the water surface and the back of the specimen shall be 3/4 ± 1/16 inch. Five initial and three after synthetic perspiration specimens shall be tested.

2/ The back side of the test cloth shall face the water. The free stream air velocity shall be 550 ± 50 FPM as measured 2 inches below the fabric specimen. The air flow shall be measured at least 2 inches from any other surface. The test shall be run for 2 hours and weight measurements shall be taken at only the start and completion of the test. Five specimens shall be tested. The specimen shall be sealed in any manner which prevents wicking and/or leaking of water out of the cup.

3/ The water pressure shall be applied to the face side of the test cloth.

4/ Except that the specimens shall be stretched at 20 pounds.

5/ The abrasion test shall be conducted in multidirectional mode using the face side of the test cloth as the abradant. A load of 6 pounds shall be applied to the abradant. The test shall be completed at 10,000 cycles.

6/ The water permeability shall be measured as specified in Method 5516 of FED-STD-191, except that the face side of the test cloth shall contact the water. The hydrostatic head shall be 50 centimeters and shall be held for 5 minutes. The report shall only include measurement of the appearance of water drops. Leakage is defined as the appearance of water any place within the 4-1/2 inch diameter test area. The test may be performed using any device which tests the same specimen area at the equivalent pressure. In cases of dispute, the apparatus described in Method 5516 of FED-STD-191 shall be used.

TEST PROCEDURES

A - Accelerated laundering test. The test procedure shall be in accordance with FED-STD-191 test method 5614, except the following deviations shall apply: Five (5) specimens containing

predominantly Black print, each 4-1/2 inches by 3 inches, shall be cut from the test fabric and then folded in half, with the face side out, to form a bag 2-1/4 by 3 inches. Machine stitch the open edges together (seam allowance no more than 1/4 inch) to form a bag leaving an opening (approximately one inch in length). Through the opening add 35 stainless steel spheres. Close the bag by stapling or stitching. Place the bag in a stainless steel cylinder (one bag per cylinder) without the color transfer cloth, add 50 ml of P-D-245, Type II detergent solution (0.5 percent by weight detergent solution) and loo stainless steel spheres and close tightly. Place the stainless steel cylinder in a preheated Launder-Ometer set at a water bath temperature of 160 $\pm$ 5OF. Agitate cylinder for one (1) hour maintaining a constant temperature. At the end of the laundering cycle, remove the bag from cylinder and rinse each bag thoroughly in a beaker, in running tap water at 100 $\pm$ 5OF for five (5) minutes with occasional stirring or hand squeezing. Remove excess water by squeezing in hand (not extracting) and then dry bag in automatic tumble dryer set on permanent press cycle, 150°-160° F for fifteen (15) minutes (more than one bag can be dried together). If the bag breaks open to release the contained spheres at any time during the test, the test shall be considered invalid and another bag specimen shall be prepared and tested. Remove all spheres from the bag and evaluate each face of the bag without pressing or ironing the bag. Each face of the laundered bag shall be compared to the original sample (unlaundered) in accordance with AATCC Evaluation Procedure 1 for evaluation of Gray Scale for Color Change and the rating shall be based on the portion of the Black print exhibiting the most color loss. The lower of the two ratings of each bag shall be recorded as the result for the bag. Failure of any of the five (5) bags to meet the required rating, shall be considered a test failure.

B - <u>Spectral reflectance test</u>. Reflectance data shall be obtained from 600 to 860 nm relative to a barium sulfate standard, the preferred white reference standard. other reference white standards may be used provided they are calibrated to an absolute white; e.g., Halon, magnesium oxide or vitolite tile. The spectral bandwidth at 860 nm shall be less than 26 nm. Reflectance measurements shall be made using either the monochromatic or polychromatic mode of operation of a spectrophotometer. When the polychromatic mode is used, the spectrophotometer shall operate with the specimen diffusely illuminated with the full emission of a source that simulates either CIE Source A or CIE Source D65. Each shade of the pattern shall be measured as a single layer of cloth backed with six layers of outer shell material of the same shade. Readings will be taken on a minimum of two different areas and the data averaged. The specimen shall be viewed at an angle no greater than 10 degrees from normal with specular component included. Photometric accuracy shall be within 2 nm. The standard aperture size used in the color measurement device shall be 1.0 to 1.25 inches in diameter. Any color having spectral reflectance values falling outside the limits at four or more of the wavelengths specified in the following table shall be considered a test failure.

Spectral Reflectance Requirements
Reflectance Values (percent)

Wavelength Nanometers	Black 357 Min.	Black 357 Max.	Light Green 354 Min.	Light Green 354 Max.	Dark Green 355 and Brown 356 Min.	Dark Green 355 and Brown 356 Max
600			8	20	3	13
620			8	20	3	13
640			8	20	3	13
660			8	20	3	13
680			8	36	3	22
700		20	14	60	6	46
720		30	26	78	20	60
740		33	40	90	30	80
760		33	50	92	32	88
780		34	55	92	32	90
800		34	55	92	32	90
820		35	55	92	32	90
840		35	55	92	32	90
860		35	55	92	32	90

C - Water permeability and moisture vapor transmission rate after perspiration test. The specimen, 8 inches by 8 inches, shall be cut and exposed to synthetic perspiration as follows: The synthetic perspiration solution shall be made up in a 500 ml glass beaker by combining 3.0 grams sodium chloride, 1.0 gram trypticase soy broth powder, 1.0 gram normal propyl propionate, and 0.5 gram of liquid lecithin. Add 500 ml of distilled water, add a magnetic stirring bar, and cover the beaker. Place the beaker on a combination hot plate/magnetic stirrer apparatus. While stirring, heat the solution to 500C until all ingredients are dissolved. While stirring, cool the solution to 350C, remove cover, and dispense immediately with a pipette or other suitable measuring device. Dispense 2 ml of perspiration solution at 350C onto the center of an 8 inch by 8 inch by 1/4 inch glass plate. Place the specimen on the glass plate with the knit side facing the glass. Dispense an additional 2 ml of the synthetic perspiration solution onto the center of the specimen. Place an 8 inch by 8 inch by 1/4 inch glass plate on top of the specimen with a 4 pound weight positioned in the center. After 16 hours, remove the specimen (do not rinse) and air dry the specimen before testing. Test the specimen for water permeability or moisture vapor transmission rate, as applicable.

D - The specimen, 8 inches by 8 inches, shall be laid flat, face side up, on a glass plate, 8 inches by 8 inches by 1/4 inch. Three drops of the test liquid (i.e., DEET, diesel) shall be applied to the center of the specimen. A glass plate of the same dimensions shall be placed on the specimen and a four (4) pound weight placed in the center of the glass plate of the assembly. After 16 hours, remove the specimen and test immediately for hydrostatic resistance or

water permeability, as applicable.

E - Physical surface appearance laundering test. Place 2 + 0.2 pounds of the finished, test cloth and, if needed, ballast in an automatic washing machine set on permanent press cycle, high water level and warm (100 + 100F, -00 F) wash temperature. Each sample unit, 48 inches in length by full width, shall be cut in half across the width of the fabric. one half of the sample unit (24 inches) will be laundered and the other half retained for final evaluation (unlaundered). Place 0.5 ounces (14 grams) of detergent conforming to Type II of P-D-245 into the washer. The duration of each laundering cycle shall be 30 + 5 minutes. After laundering, place sample and ballast in an automatic tumble dryer set on permanent press cycle, 150°-160° F, and dry for approximately 15 minutes. Conduct 20 laundering and drying cycles. After each drying cycle, examine both sides of the cloth for changes in physical surface appearance. Sample shall show no changes in physical surface appearance when compared to the unlaundered sample. The laundering equipment, washer and dryer, shall be in accordance with AATCC test method 135.

F - Procedure E except for the sample size and the evaluation for physical surface appearance shall be used to launder samples for one (1) cycle prior to testing for spray rating and resistance to organic liquids and to launder synthetic perspiration, DEET, diesel, weapons lubricant, motor oil and J-8 contaminated samples for one (1) cycle prior to testing for hydrostatic resistance and water permeability, as applicable.

G - Water Permeability after flex (700F) test. one specimen, eight (8) inches by twelve (12) inches, shall be cut from the sample unit with the eight (8) inch dimension in the indicated direction (warp or filling as applicable). The specimen shall be conditioned and flexed as specified in Method 2017 of FED-STD-101 except the specimen shall not be aged, the short edges shall not be heat sealed or otherwise joined, and the specimen shall be flexed for 1500 cycles. Two six (6) inch by eight (8) inch specimens shall be cut from the eight (8) inch by twelve (12) inch flexed specimen and tested for water permeability.

H - Water permeability after cold flex test. The water permeability after cold flex test shall be as specified in procedure G except that the eight (8) inch by twelve (12) inch specimen shall be mounted on the flex test apparatus, placed in a test chamber at the specified temperature for one hour, and then flexed in the test chamber at the specified temperature. At the end of the flexing cycle, the specimen shall be removed from the test chamber and conditioned prior to testing for water permeability.

J - High humidity test. Three (3) specimens, four (4) inches by four (4) inches, shall be tested and shall be laid flat, back side up on a supporting plate and the assembly placed in a desiccator containing water in the lower portion. The water level shall be approximately one (1) inch below the specimens. The lid of the desiccator shall be put in place and the desiccator placed in a circulating air oven having a temperature of 160 OF $\pm$ 2 OF for a period of seven (7) days. At the end of the aging period, each specimen shall be removed from the desiccator and tested

immediately in accordance with ASTM D-3393 with the water pressure being applied to the face side of the material.

K - Water permeability after seam tape. A square sample of material, 24 inches by 24 inches, shall be cut with one diagonal of the specimen parallel to the warp direction of the material. The square sample shall then be cut in half to form two (2) rectangular pieces of dimensions 12 inches by 24 inches. The two (2) rectangular pieces shall be superimposed with face sides together and then seamed along one, 24 inch long dimension. The bias seam (relative to the fabric) shall be constructed as a Type SSa-1 seam using a Type 301 stitch, size B thread of V-T-285, 10 to 13 stitches per inch and a 1/4 (max.) seam allowance. The seam shall then be seam taped with a suitable seam tape compatible with the material. The seam tape shall be one (1) inch (± 1/16 inch) wide and shall be applied over the sewn seam on the back side of the material as one continuous piece. The taped, seamed test sample shall be cooled for a minimum of one (1) hour prior to further testing. The test sample shall be laundered for five (5) cycles in accordance with Test Procedure E and then visually examined for any sign of tape lifting, curling, bubbling, puckering or separation along the tape edges or tape width (the occurrence of any of these visual defects shall be considered a test failure). Three (3) test samples shall be prepared and evaluated. Two (2), eight (8) inch by eight (8) inch, test specimens (maximum) shall be cut from the center 16 inch square area of each test sample; the seam taped seam shall be centered in each test specimen. Five (5) test specimens shall then be tested for water permeability in accordance with AATCC #127 6/ with the seam centered in the test area and using a 50 centimeter hydrostatic pressure head held for a period of 10 minutes.